Representing CMIP5 land use/land cover in the Community Land Model (CLM4.0)

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Terrestrial Science Section

Simulating the Biogeochemical and Biogeophysical Impacts of Transient Land Cover Change and Wood Harvest in the Community Climate System Model (CCSM4) from 1850 to 2100.

Lawrence, P. J., J. J. Feddema, G. B. Bonan, G. A. Meehl, B. C. O'Neill, S. Levis, D. M. Lawrence, K. W. Oleson, E. Kluzek, K. Lindsay, and P. E. Thornton (2012) *Journal of Climate*, **25**, 3071–3095

1. CMIP5 – Land Cover Change and Wood Harvest – Overview

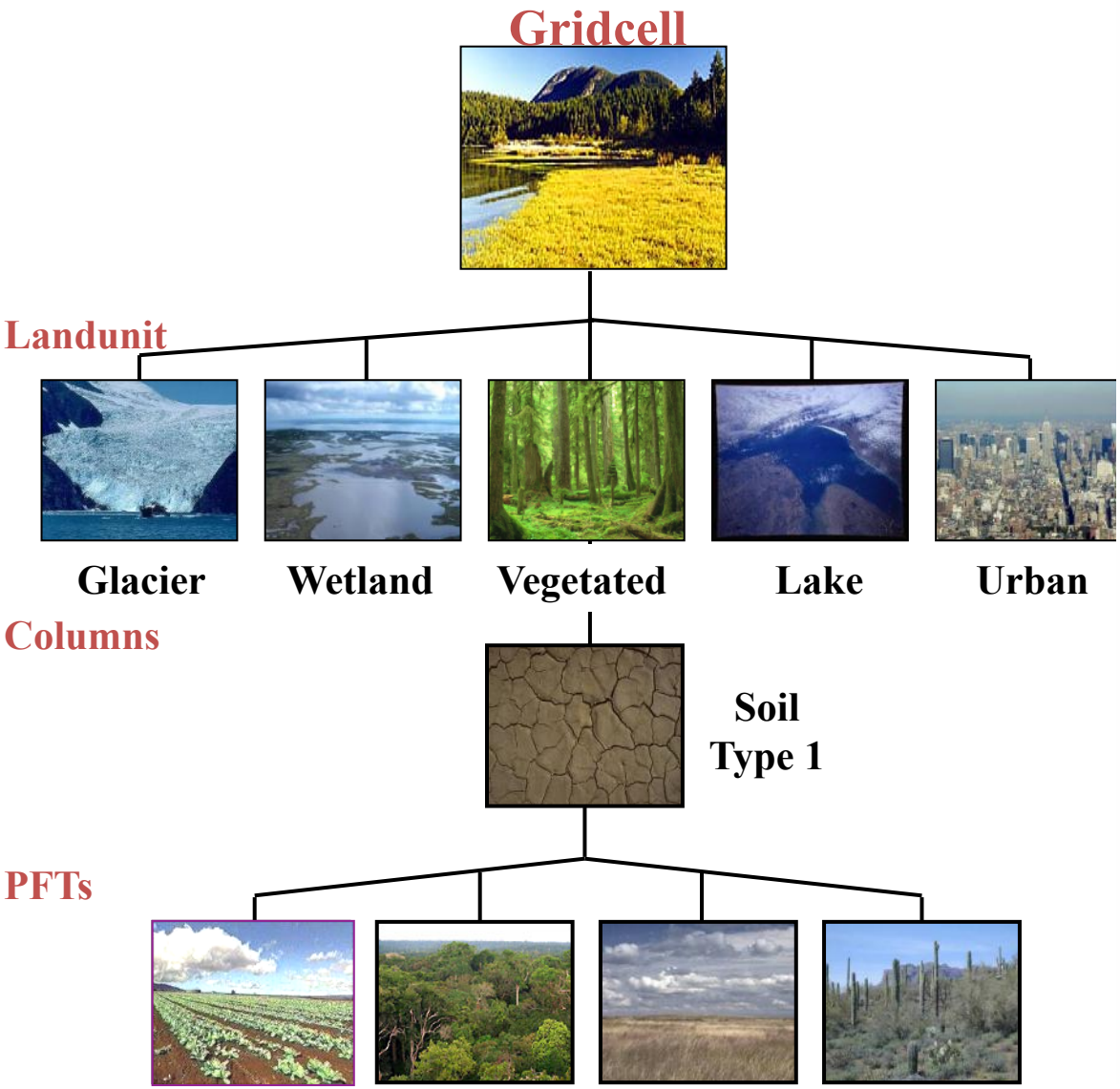
1. CMIP5 protocol has Land Cover Change is a component of climate forcing for the 1850 – 2005 Historical period and for the 2006 – 2100 Representative Concentration Pathway (RCP) periods

2. For each Historical and RCP period land use and land cover change were described through harmonized annual changes from the Global Land Model (GLM) of the four basic land units of:

    - Primary Vegetation (Prior to Human Disturbance)
    - Secondary Vegetation (Disturbed then abandoned or managed)
    - Cropping
    - Pasture (Grazing Lands)

3. Harvesting of biomass was also prescribed for both primary and secondary vegetation land units both in terms of fraction of area and total carbon harvested for old and young forests and for non forest.

2. Land Cover Change in the CLM4 subgrid tiling



Plant Functional Types:

0. Bare

Tree:

1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:

9. Broadleaf Evergreen Shrub, Temperate
10. Broadleaf Deciduous Shrub, Temperate
11. Broadleaf Deciduous Shrub, Boreal
12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop

3. CMIP5 Transient Land Cover in CLM 4 PFTs

1. To include the historical and RCP land cover change pathways in CLM4 we need to take the annual changes in UNH land units and make an annual time series of changing Plant Functional Types

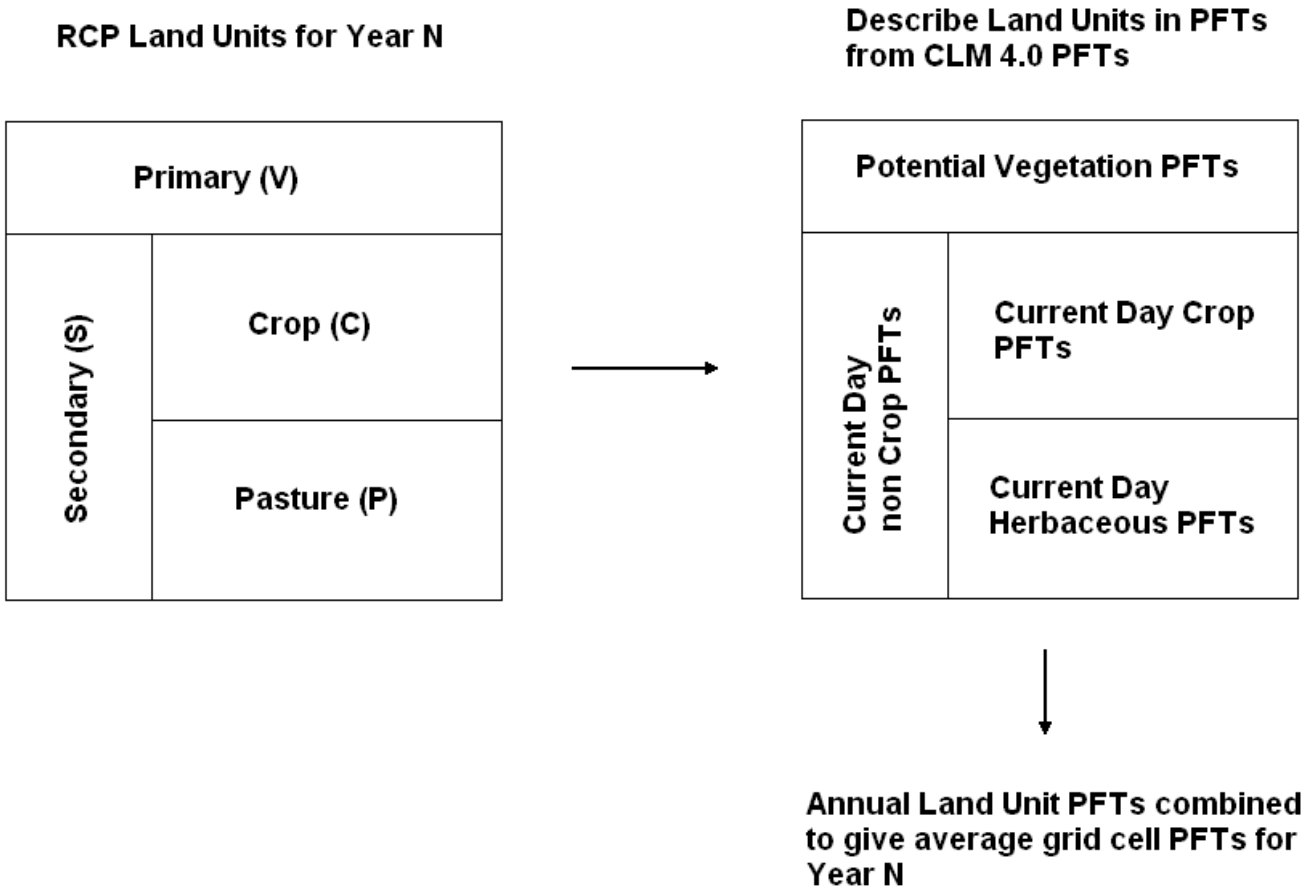
2. To make this transition we describe the PFT composition of the individual UNH land units of each grid cell based on our Current Day and Potential Vegetation CLM 4.0 parameters for that grid cell

3. Current Day (2000) CLM 4 land surface parameters are derived from MODIS satellite data as described in *Lawrence and Chase* (2007)

4. Potential vegetation CLM 4 parameters are bio-climatically modeled as described in *Lawrence and Chase* (2010)

5. Wood harvest parameters on Tree PFTs also were calculated from the five harvest prescriptions.

3. CMIP5 Transient Land Cover in CLM 4 PFTs Method – GLM 0.5^{O}



3. CMIP5 Transient Land Cover in CLM 4 1850 – 2100 Example

Example Transformation from Land Units to PFTs with wood harvest for a grid cell in Year 2100

1. GLM Year 2100 Land Units — Transformation

Primary	- 10%	Primary Harvest	- 1%
Secondary	- 90%	Secondary Harvest	- 4%
Crop	- 0%		
Pasture	- 0%		

GLM Year 2000 Land Units — Reference Data

Primary	- 20%
Secondary	- 20%
Crop	- 40%
Pasture	- 20%

2. CLM4 Year 2100 Land Unit Component PFTs

Primary	- Tropical Broadleaf Evergreen	- 7%
	- Tropical Broadleaf Deciduous	- 2%
	- C4 Grass	- 1%
	- Tree Harvest	- 0.9%
Secondary	- Tropical Broadleaf Evergreen	- 13.5%
	- Tropical Broadleaf Deciduous	- 58.5%
	- C4 Grass	- 18%
	- Tree Harvest	- 3.2%
Crop	- Crop	- 0%
Pasture	- C4 Grass	- 0%

CLM4 Year 2000 MODIS derived PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%

CLM4 Potential Veg PFTs

Tropical Broadleaf Evergreen Tree	- 70%
Tropical Broadleaf Deciduous Tree	- 20%
C4 Grass	- 10%

3. CLM4 Year 2100 Final Aggregated PFTs

Tropical Broadleaf Evergreen Tree	- 20.5%
Tropical Broadleaf Deciduous Tree	- 60.5%
Crop	- 0%
C4 Grass	- 19%
Tree Harvest	- 4.1%

CLM4 Year 2000 calculated Secondary PFTs

Tropical Broadleaf Evergreen Tree	- 15%
Tropical Broadleaf Deciduous Tree	- 65%
C4 Grass	- 20%

3. CMIP5 Transient Land Cover in CLM 4 PFTs

1. The CLM Transient LCC generation method ensures that Crops are prescribed directly from GLM

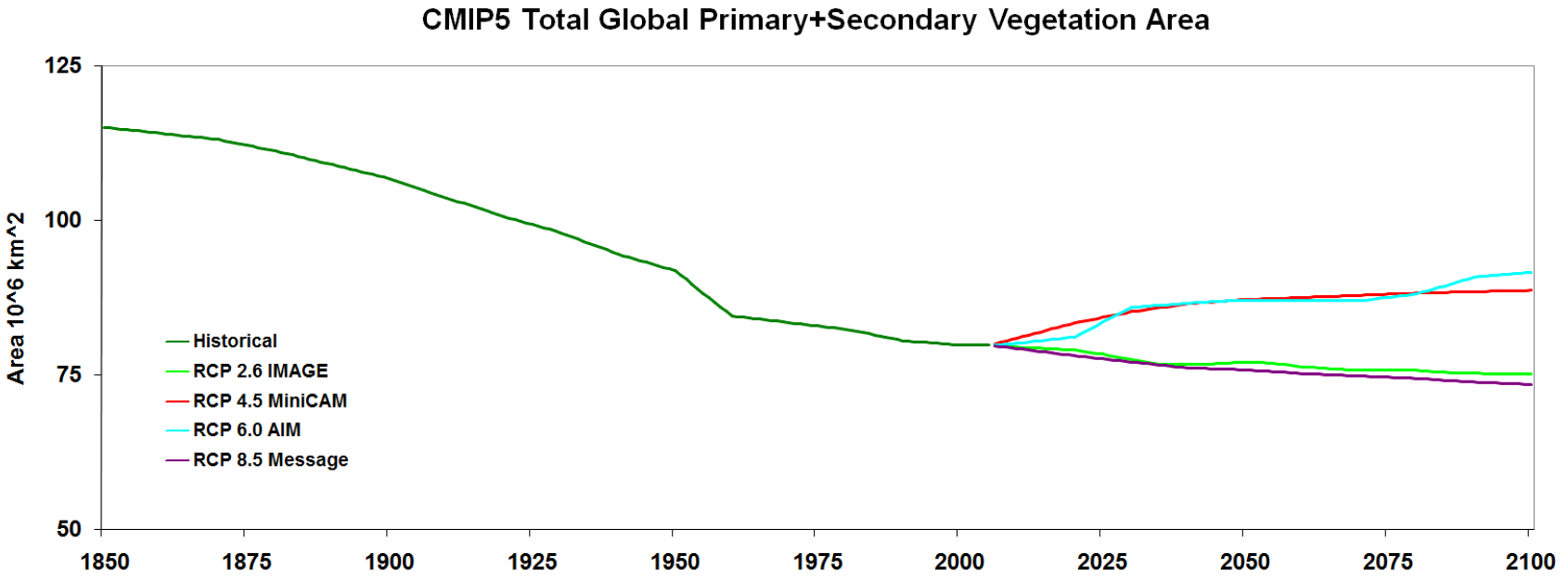
2. Ensures Current Day (2000) natural vegetation distributions are consistent with Current Day MODIS Forest, Shrub and Grass distributions while accounting for the GLM Crop and Pasture (Transient hits Satellite in 2000)

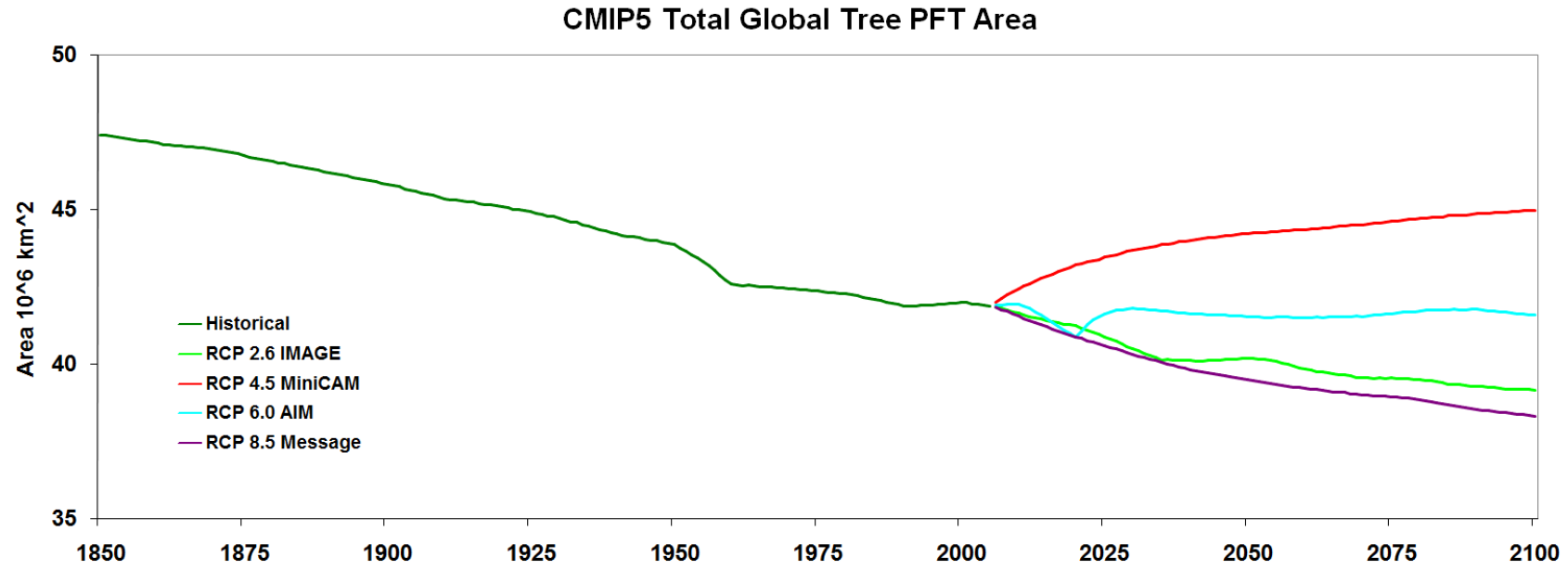
3. Ensures Pasture distributions can only reach current day or potential vegetation density values.

4. There is however significant information loss from the IAM to the ESM in this process as the composition of Primary, Secondary, Crop and Pasture vegetation needs to be described by each ESM group independently.

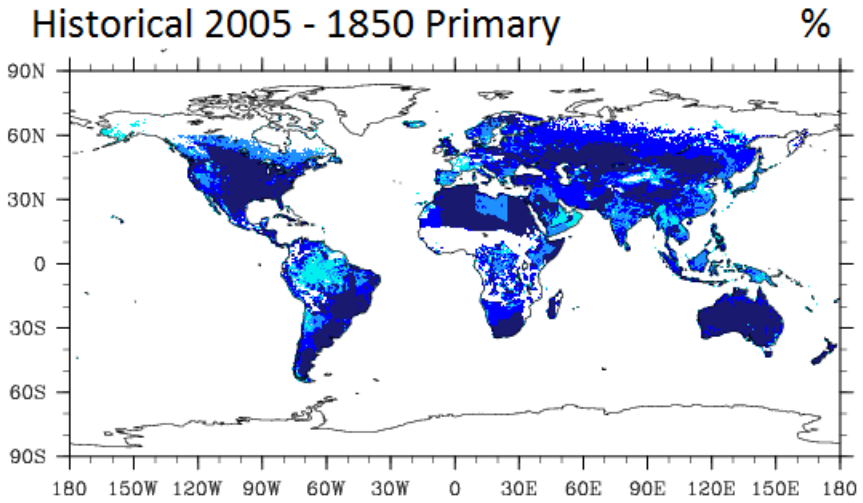
5. We also found wood harvest parameters have large inconsistencies for RCP 6.0 and RCP 8.5 due to differences in carbon densities between GLM, the IAMs and the CLM4 CN

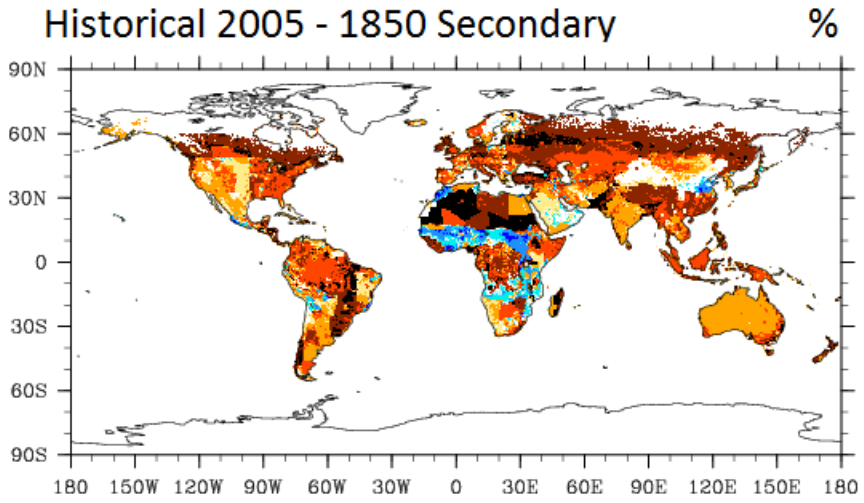
4. CMIP5 Transient Land Cover in GLM LUs and CLM 4 PFTs

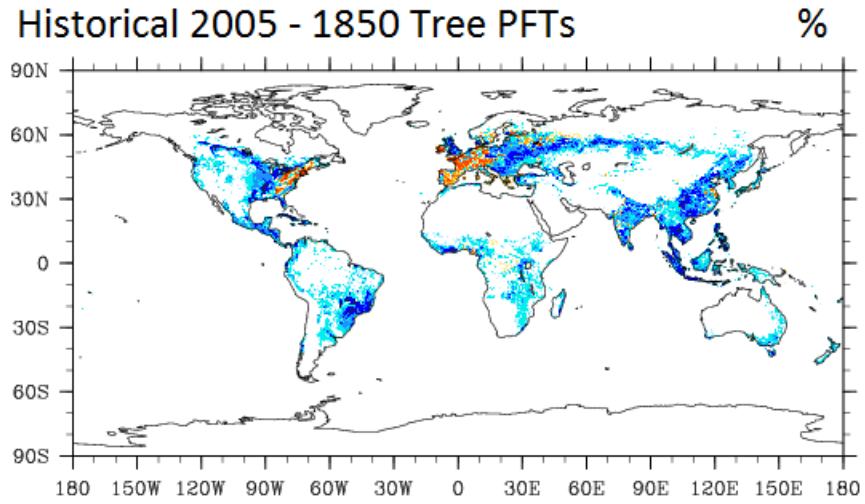


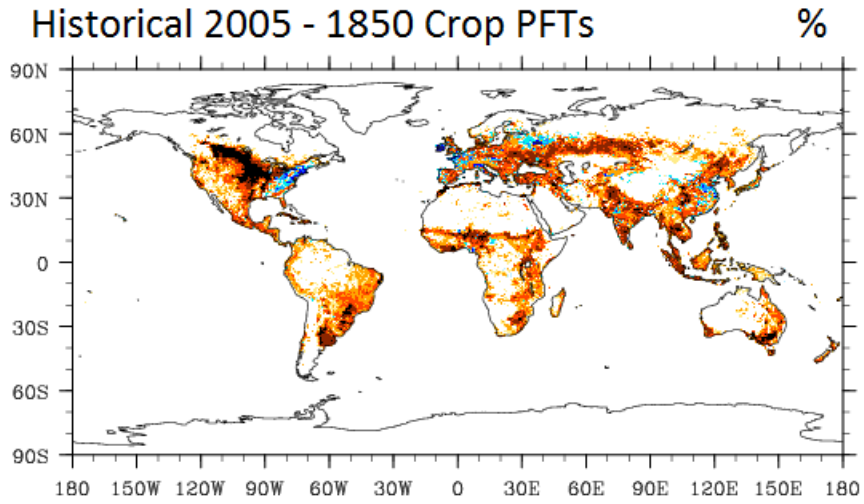


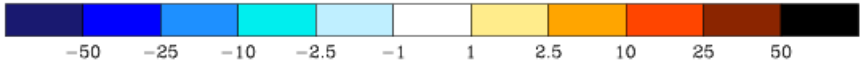
4. CMIP5 - Historical Land Cover Change – LUs and PFTs %area











4. CMIP5 Historical Transient Land Cover in CLM 4 PFTs

1. Large GLM Land Unit changes in sparsely vegetated areas such as Sahara, Central Australia, and Eurasia but these areas have very little actual vegetation change in CLM PFTs

2. Meiyappan and Jain (2012) also showed there are considerable differences between MODIS forest area and GLM forest area for 2005. Issues with base year for Historical and IAM Land Cover.

MODIS Current Day Forest Area (2005)

GLM Current Day Forest Area (2005)

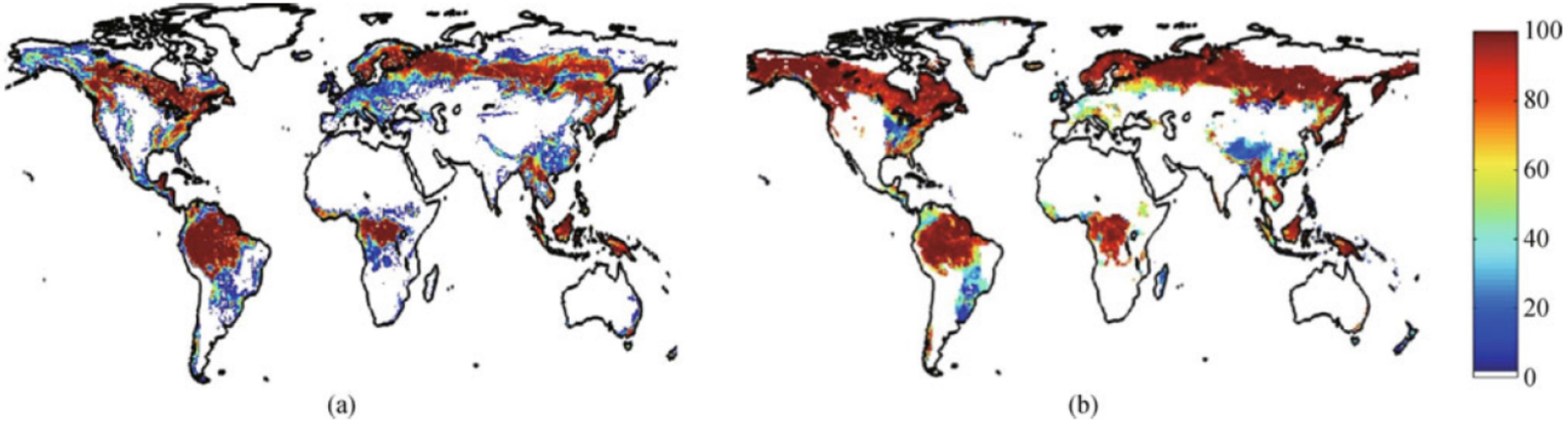
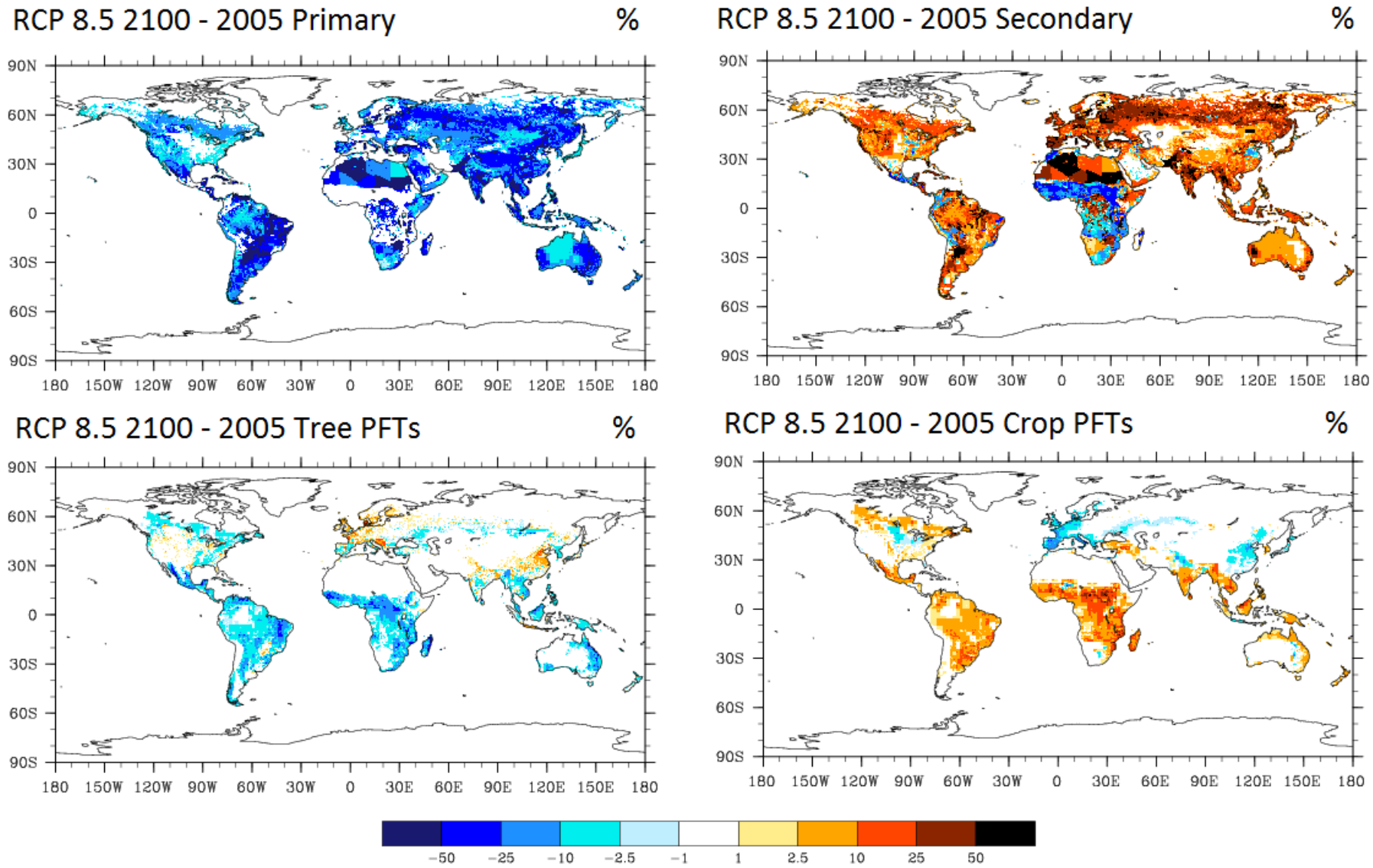


Fig. 1 Global distribution of forest area during 2005 based on (a) MODIS-IGBP data, and (b) estimates by Hurtt et al. (2011) (Unit: % per grid cell area)

5. CMIP5 – RCP 8.5 Land Cover Change – LUs and PFTs %area



5. CMIP5 RCP 8.5 Transient Land Cover in CLM 4 PFTs

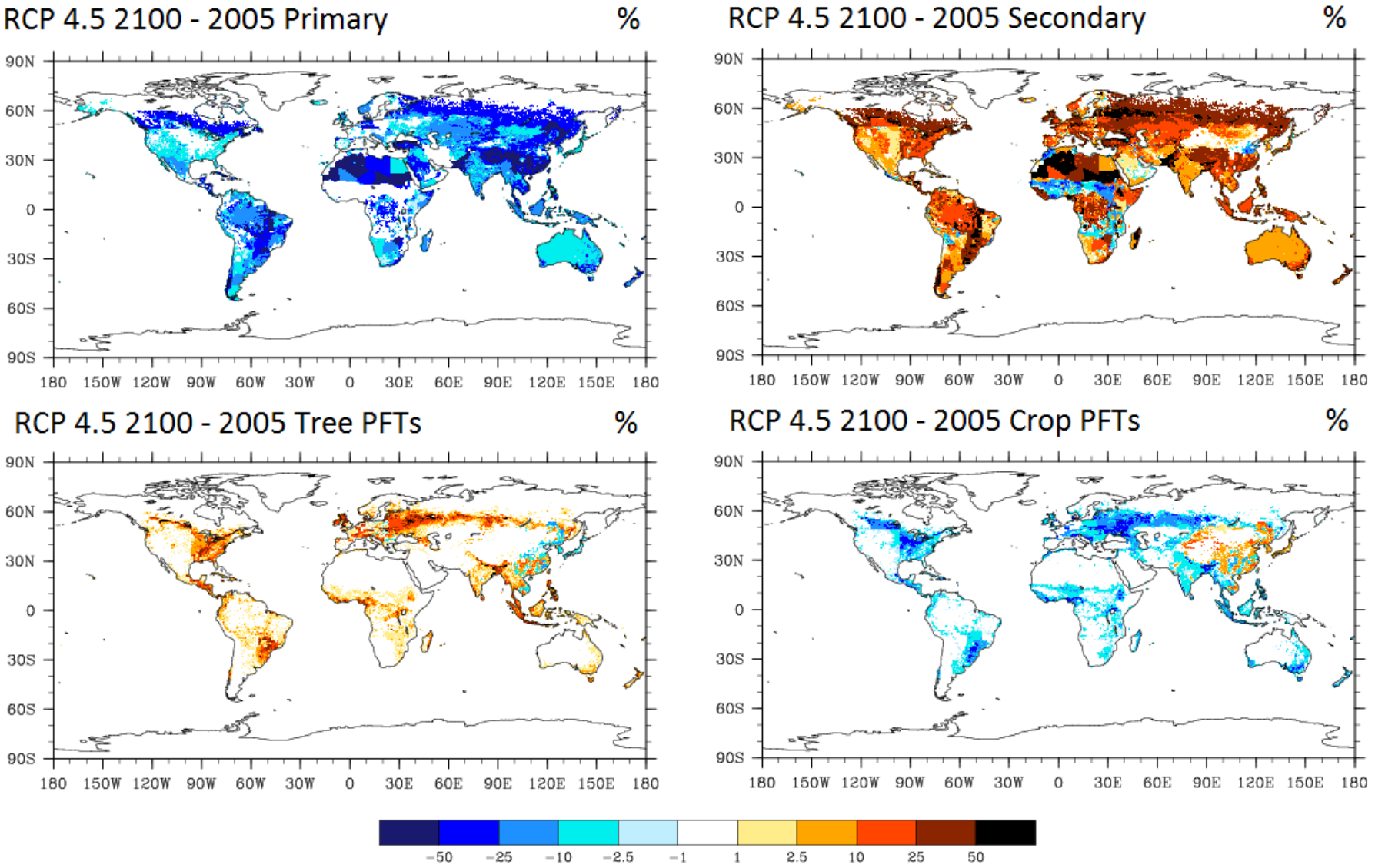
1. Primary to Secondary transition can only be from Potential Vegetation to Year 2000 derived Secondary PFT composition. This means only one PFT transformation possible for that Land Unit transformation regardless of when it occurs or what was the human activity involved.

2. This limits the ability to prescribe human land uses such as agro forestry or biofuel production beyond crops.

3. Primary or Secondary to Crop or Pasture transitions more effective in their prescription as Trees are effectively removed for that area and replaced with the crops or grass.

4. There are also significant issues with wood harvest for RCP 8.5 and RCP 6.0 which will be discussed in more detail later in the talk.

6. CMIP5 – RCP 4.5 Land Cover Change – LUs and PFTs %area



6. CMIP5 RCP 8.5 Transient Land Cover in CLM 4 PFTs

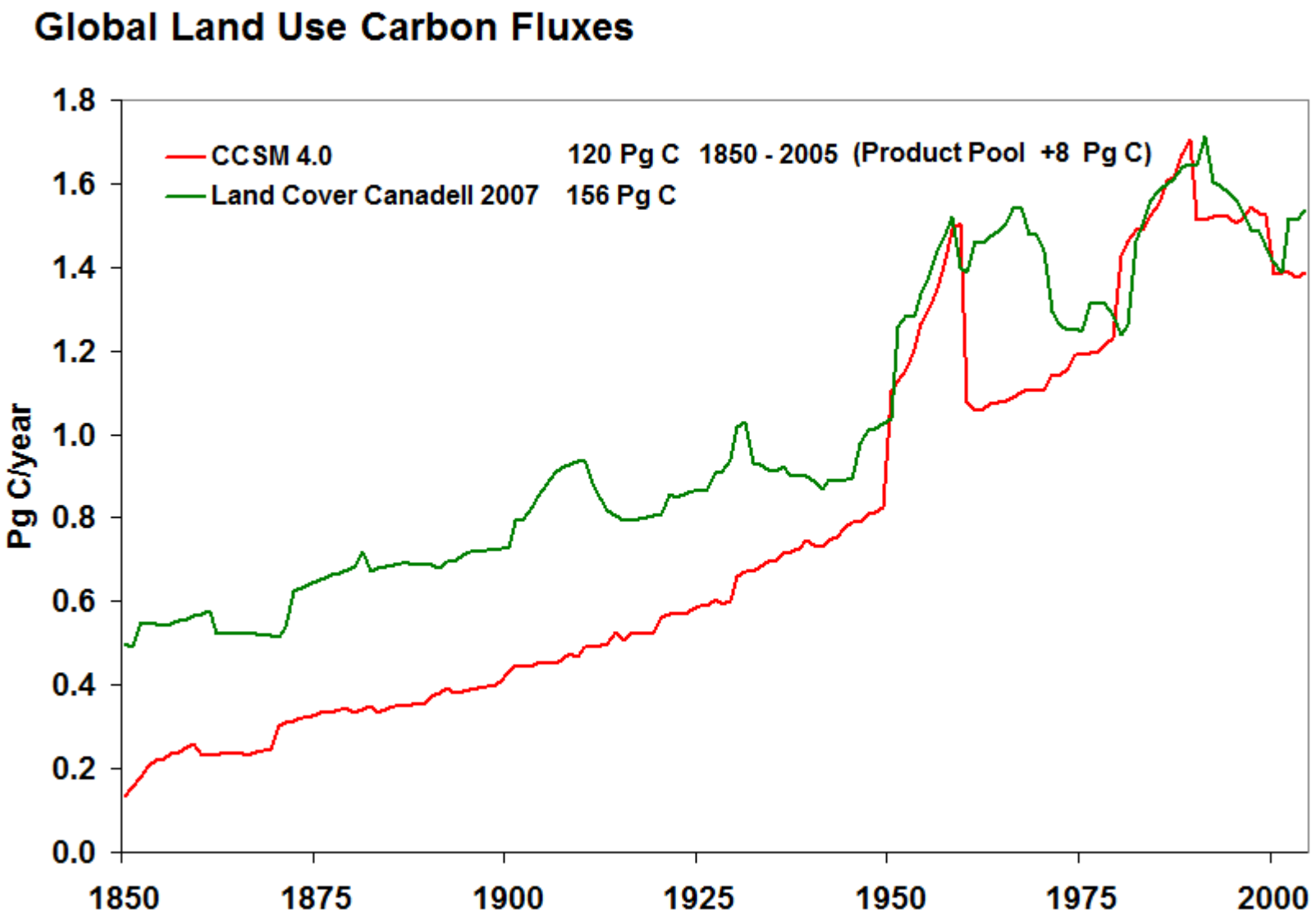
1. Again Primary to Secondary transition can only be from Potential Vegetation to Year 2000 derived Secondary PFT composition. This means only one PFT transformation possible for the Land Unit transformation.

2. Afforestation through Crop or Pasture transforming to Secondary Land Units is possible, however it requires the Secondary Land Unit to have been forested in 2000. In areas where the Secondary Land Unit was not forested it is impossible to put Trees into these areas with these methods.

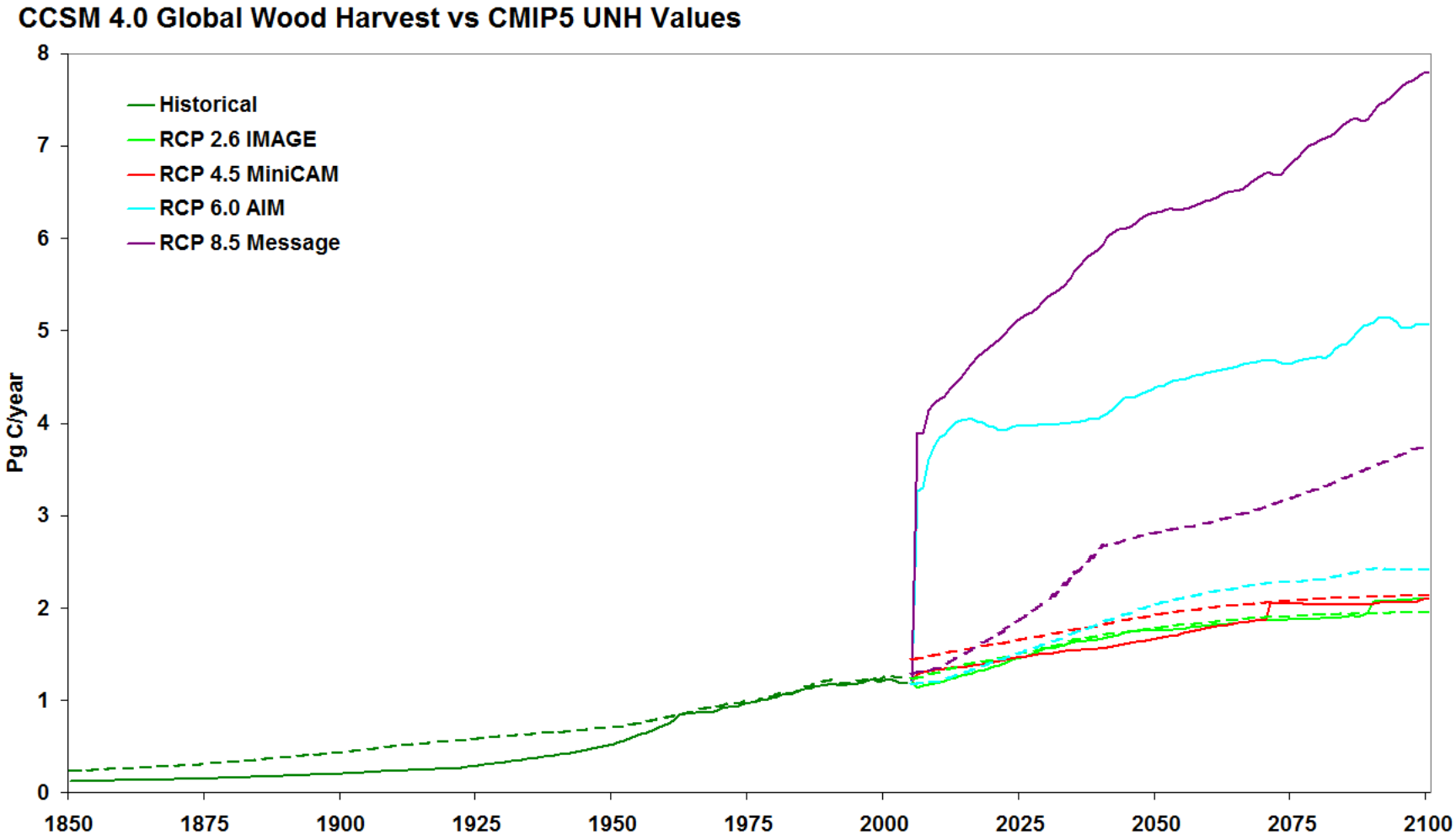
3. It is impossible to perform afforestation on land that is not Crop or Pasture as there is no PFT impact on Secondary to Secondary transformation.

4. These two points limit the afforestation in GCAM for RCP 4.5 being communicated to the CLM PFT parameters.

7. LCC in CCSM 4 – Coupled Climate & Prescribed CO_2



7. CMIP5 Wood Harvest in CCSM 4.0 vs GLM Total Carbon Harvested



7. CMIP5 Wood Harvest in CCSM 4.0 vs UNH Prescribed

1. The Historical, RCP 2.6 and RCP 4.5 time series all have good agreement for carbon harvested in CCSM 4.0 with the Tree PFT wood harvest parameters and with the GLM total global carbon harvest.

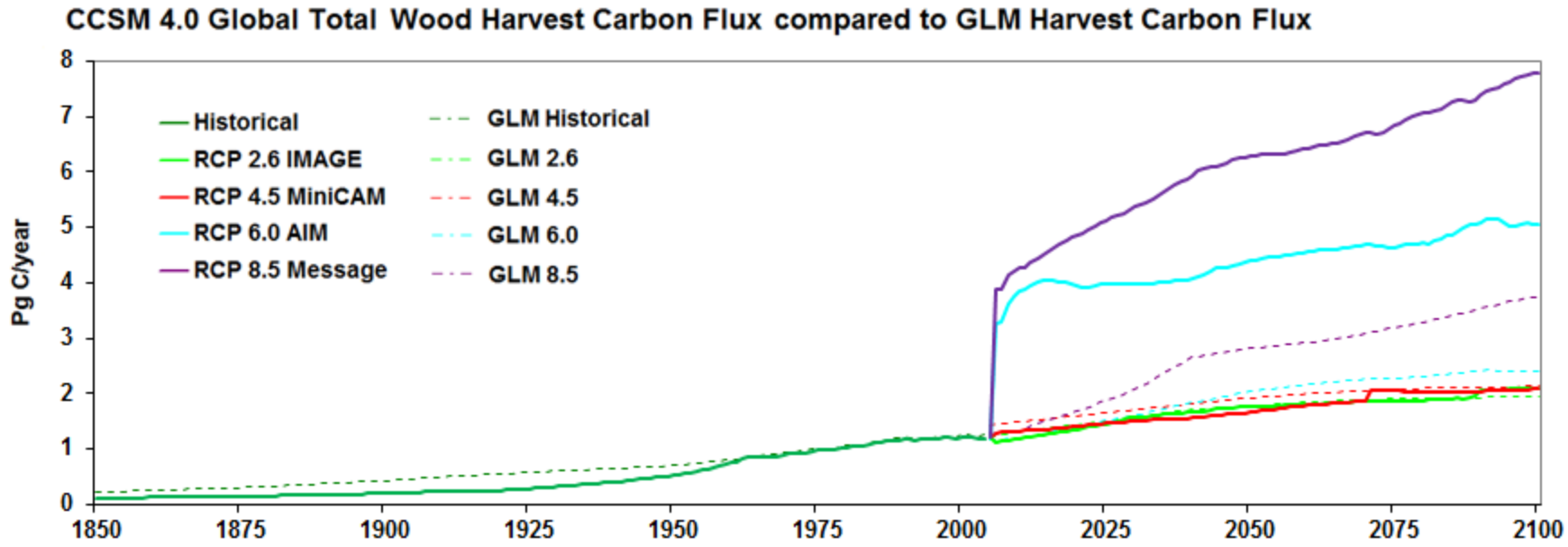
2. The RCP 6.0 and RCP 8.5 simulations both have very large differences.

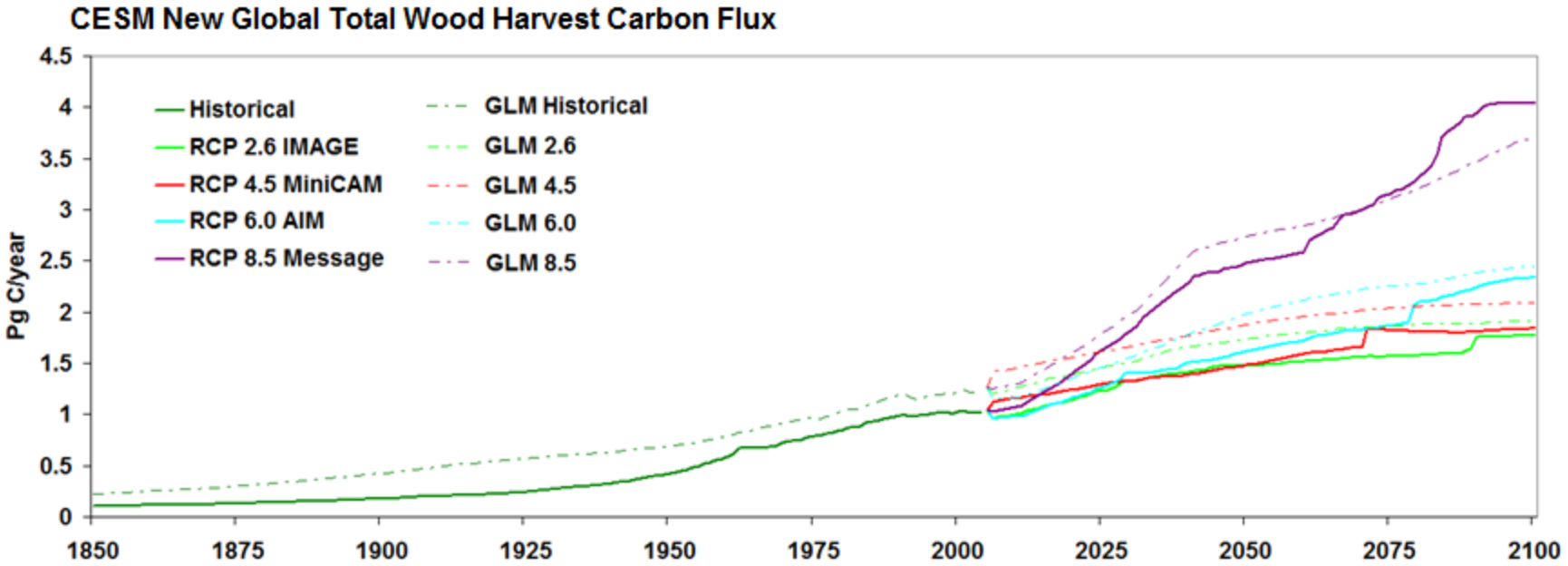
3. After a series of telephone meetings it was found that RCP 6.0 and RCP 8.5 both had spatially explicit wood harvest prescribed from AIM and MESSAGE while for RCP 2.6 and RCP 4.5 IMAGE and GCAM provided regional targets that were spatially downscaled in GLM.

4. The spatially explicit wood harvest required GLM to find carbon in areas that the IAMs considered forested but GLM had very low tree and carbon densities and therefore required very large harvest areas. As these same areas were forested in CLM the large harvest area combined with much higher carbon densities resulted in very large wood harvest amounts.

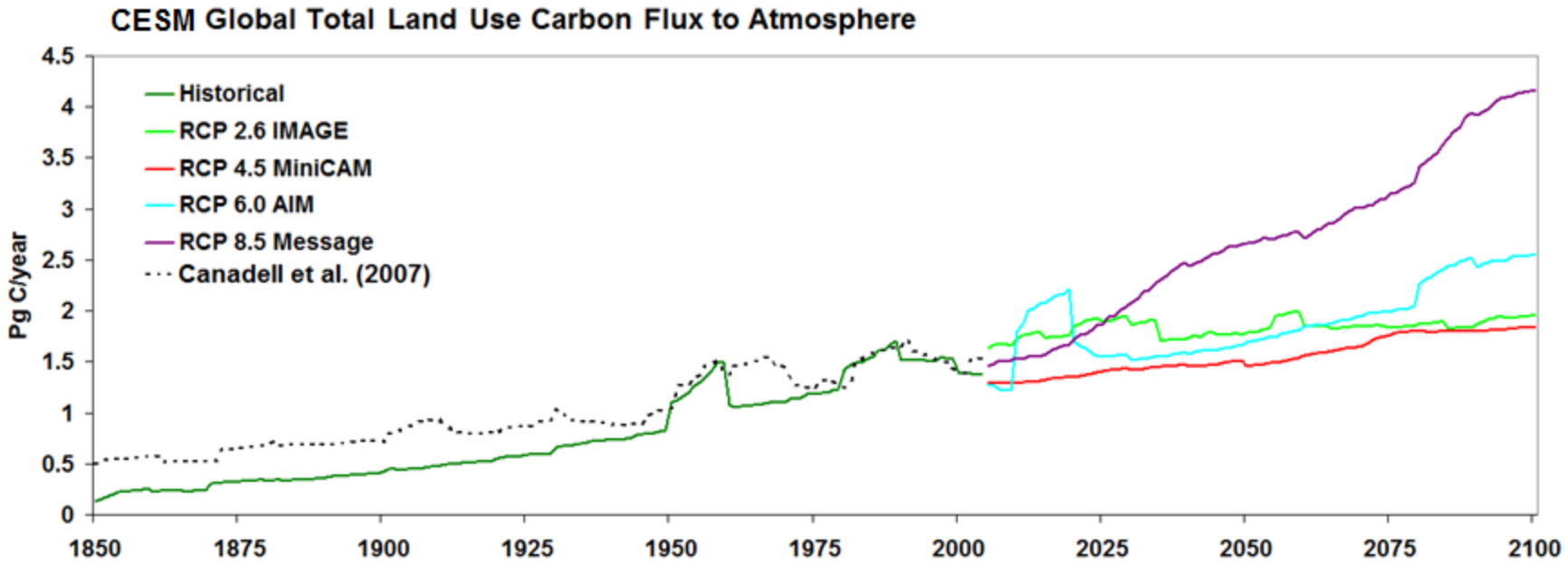
5. GLM was rerun for RCP 6.0 and RCP 8.5 with regional harvest targets. These runs met the wood harvest targets with much smaller harvest areas providing a solution for this issue in the later CESM CMIP5 simulations.

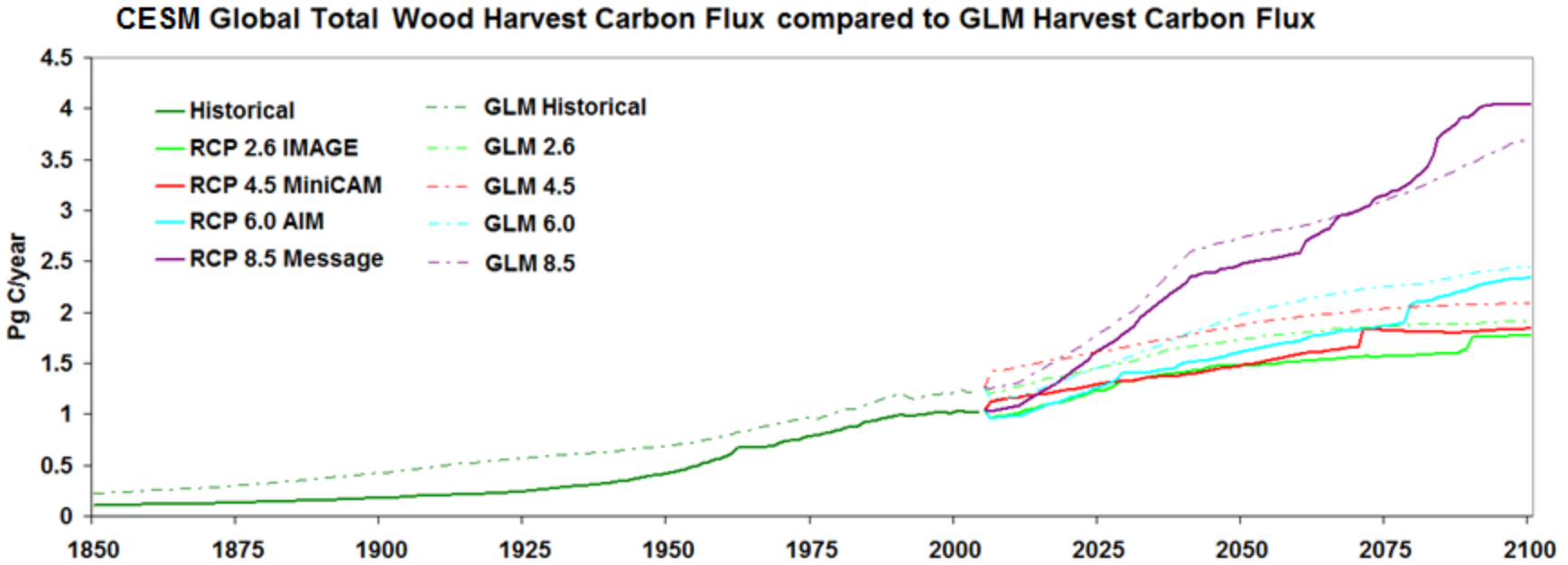
7. LCC in CCSM 4 – Coupled Climate & Prescribed CO2



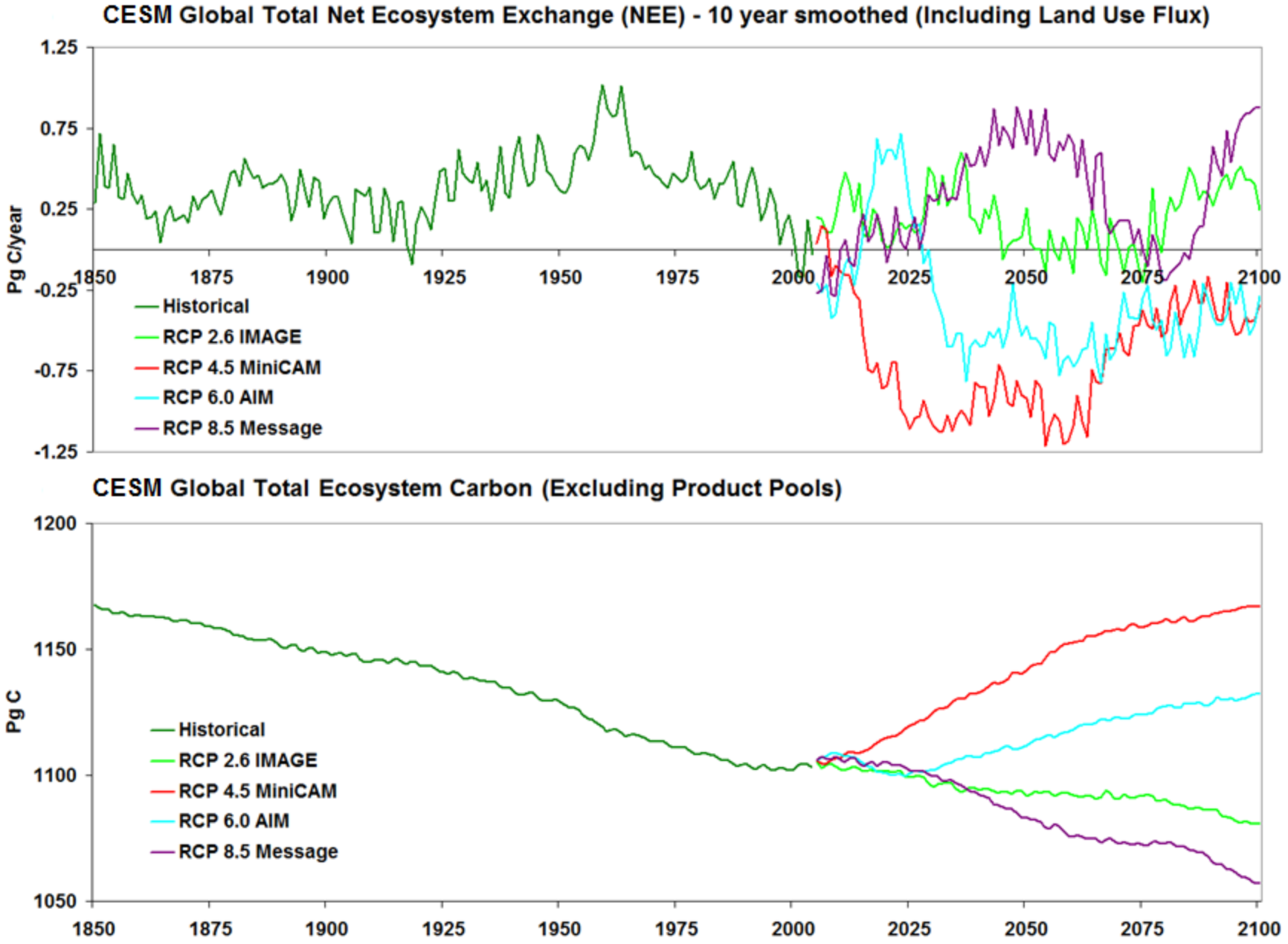


7. LCC in CCSM 4 – Coupled Climate & Prescribed CO2





8. LCC in CCSM 4 – Coupled Climate & Prescribed CO2



8. Conclusions and Ideas for LCC in CMIP6

1. Process partially worked in that elements of Land Cover Change and Wood Harvest were represented in CESM CMIP5 climate simulations

2. From an ESM perspective the CMIP5 LCC process was mysterious and undocumented until after the CESM climate simulations were completed

3. The four Land Units of Primary, Secondary, Crop and Pasture lose much of the information generated by the IAM so are unable to represent many elements of Land Use and those impacts on Land Cover Change

4. Afforestation was partially represented for Crop or Pasture transformation to Secondary land but only in areas where the Secondary land in 2000 was forested

5. Unable to capture afforestation on Secondary land as there is no PFT transition from Secondary to Secondary.

8. Conclusions and Ideas for LCC in CMIP6 - Continued

6. Large issues with base year Land Cover distributions with impacts on carbon densities between the IAMs, GLM, and ESMs. This lead to large wood harvest issues for RCP 6.0 and RCP 8.5

7. Thinking toward CMIP6 a much wider range of human activities and their impacts need to included to fully represent the impacts of human activities on surface energy budgets, hydrology and the carbon cycle. Specific examples of information passed to the ESMs should include:

   - Multiple cropping types
   - Irrigation
   - Biofuels – crops and other mechanisms
   - Afforestation explicitly specified
   - Conservation and protected areas management (REDD+)
   - Urban and peri-urban expansion and adaptation (Green space, etc)